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Environmental impacts of German food consumption and food losses

Ulrike Eberle[1] **· Jacob Fels**[2]

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Abstract

Purpose The objective was to assess the environmental burden of food consumption and food losses in Germany with the aim to define measures to reduce environmentally relevant food losses. To support the finding of measurements, the study provides differentiated information on life phases (agriculture, processing, retailer, and consumption), consumption places (in-house and out-of-home), and the average German food basket consisting of eight food categories.

Methods In order to obtain information on the environmental impacts of German food consumption, the study analyzed the material flows of the food products in the German food basket starting from consumption phase and going backwards until agricultural production. The analysis includes all relevant impact categories such as GWP, freshwater and marine eutrophication, particular matter formation, and agricultural land and water use. The life stages consumers, retail, wholesale, food production, and agriculture have been taken into account. Furthermore, transports to and within Germany have been considered. Consumption and production data have been taken from the German income and consumption sample, German production and trade statistics, and studies recently carried out on food losses. In order to model German food consumption, some simplifications had to be done.

Results and discussion Results show that German food consumption is responsible for 2.7 t of greenhouse gases per person and year. Fourteen cubic meters of blue water is used for agricultural food production per person, and 2673 m^2 of agricultural land is occupied each year per German for food consumption. Between 14 and 20 % of the environmental burdens (depending on the impact category) result from food losses along the value chain. Out-of-home consumption is responsible for 8 to 28 % of the total environmental impacts (depending on the impact category). In particular, animal products cause high environmental burdens. Regarding life cycle phases, agriculture and consumption cause the highest impacts: together, they are responsible for more than 87 % of the total environmental burdens.

Conclusions The study shows that food production and consumption as well as food losses along the value chain are of high relevance regarding Germany's environmental impacts. In particular, animal products are responsible for high environmental burdens. Thus, with respect to reducing environmentally relevant food losses, measures should focus in particular on the reduction of food waste of animal origin. The most relevant life cycle phases to reduce environmental impacts are agricultural production and consumption in households and out-of-home.

Keywords Environmental impacts · Food consumption · Food losses · German food basket

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✉ Ulrike Eberle
u.eberle@corsus.de

[1] corsus-corporate sustainability, Nernstweg 32-34, 22765 Hamburg, Germany

[2] Zentrum für Nachhaltige Unternehmensführung, Universität Witten-Herdecke, Alfred-Herrhausen-Str. 50, 58448 Witten, Germany

1 Introduction

In recent years, food waste is more and more of public interest. In 2011, the documentary "Taste the Waste" came to German cinemas, and its alarming message ("half of the food is spoiled") caused disgust about our way of dealing with food in the public. In 2011 also, the Food and Agricultural Organization (FAO) published a study on global food waste with the result that about one third of the food produced at global level is spoiled. This corresponds to 1.3 billion tons per year (Gustavsson et al. 2011). At the same time, according estimations of the FAO, 925 million people were starving.[1] Also, in Germany, a study on food waste was carried out on behalf of the Federal German Agricultural Ministry (BMELV). This study came to the result that each year each German wastes 82 kg of food (Kranert et al. 2012).

The aim of the part presented here was to assess the environmental burden of food consumption and food losses in Germany along the whole life cycle.

2 Methods

In order to obtain information on the environmental impacts of German food consumption, the study analyzed the material flows of the food products in the German food basket starting from consumption phase and going backwards until agricultural production (Table 1).

2.1 The German food basket

The analysis differentiates between private consumers' food basket (in-house consumption) and the food basket of large-scale consumers such as restaurants and canteens (out-of-home consumption). Both food baskets contain the same foods but differ in quantities.

The German in-house food basket is available in official statistics (Statistisches Bundesamt 2011). It contains (without beverages and candies) 79 different foods grouped into eight food categories: "bread and cereals," "meat and meat products," "fish and fish products," "milk and dairy products," "fats and oils," "fruits," "vegetables," and "sugar" (see Tables 2 and 3). Within the study, every group is represented by a set of proxies. The proxies were chosen regarding their share within the product group and by data availability. For example, apples, oranges, and bananas represent the product group "fruits." Thus, a total of 23 proxies have been identified to represent the eight food categories: rice, wheat bread, pasta, bovine meat, pork meat, poultry meat, average meat product, fish, eggs, milk, cheese, cream, butter, plant oil, oranges, bananas, apples, mixed canned and frozen fruits, tomatoes, field vegetables, mixed canned and frozen vegetables, potatoes, and sugar.

The German food basket for out-of-home consumption contains the same products but in different quantities. Data for out-of-home consumption had to be estimated because statistics are not available. The estimation is based on the share of out-of-home consumption in relation to in-house consumption for the respective product given by Wiegmann et al. (2005) and the in-house-consumption data from Statistisches (2011).

In order to provide information on the relevance and impacts of food waste, the study differentiates between consumed and spoiled food at each life cycle stage. To avoid confusion, the eaten share of total food provided by the analyzed system is defined as food consumption. Food losses are understood as the parts of a food product that are not eaten. These include raw products, i.e., those that are not harvested, as well as losses in food processing or food waste in households. All food losses have been considered in the study without distinguishing between avoidable and unavoidable losses.[2] The only exception is meat where a differentiation between eatable meat, slaughter by-products, and meat losses has been done. Slaughter by-products have been considered separately and were not included in the calculation of the environmental burden of meat. Data for food losses have been used from two German studies carried out recently (Kranert et al. 2012; Peter et al. 2013) and from a study on behalf of the Food and Agricultural Organization (FAO) (Gustavsson et al. 2011). Figures 1 and 2 show the material flows used as basis for the calculation of the environmental impacts of German food consumption.

Detailed assignment of products to product groups is listed in Tables 2 and 3.

2.2 Scope and functional unit

By using 23 foods as representatives, the study covers the average German food consumption on a per capita level. Only beverages and candies have not been considered both for in-house and out-of-home consumption. A differentiation between in-house and out-of-home consumption as well as between food consumption and food losses has been made. The analysis starts from ready-to-consume food (cooked or prepared) and includes all downstream activities up to agriculture, namely agricultural production, food processing, retailing, and consumption. Packaging and waste treatment have not been included.

The functional unit of the study is the yearly average German consumers' ready-to-consume food basket (in-house consumption and out-of-home consumption). Reference year is 2010.[3]

2.3 Modeling

Within the study, a model has been built representing the four life cycle phases (agricultural production, processing, retailing, and consumption) for the 23 foods which have been chosen as representatives.

[1] http://www.fao.org/mdg/goalone/en/; status: 8 August 2012

[2] This was done for the reason that the characteristics "avoidable" or "unavoidable" are closely correlated with a value system that can change in the course of time and in households or restaurants that also depend on the preparation and the product. Thus, potato skins could be avoided as food loss when preparing boiled potatoes in their jacket and could not be avoided if preparing boiled potatoes.

[3] Modeling and the calculation itself were done with the software Umberto NXT LCA.

Table 1 Agriculture, processing, retail, transport, cooking, and storage data

Activity	Value	Source
Agriculture	Exact values are documented in data documentation of Jepsen and Eberle (in preparation)	Data documentation (Jepsen and Eberle, in preparation)
Transport agriculture-processing	348 km lorry transport to harbor in country of origin*; 348 km lorry transport from harbor to processing in Germany; the exact value of the vessel transport depends on country of origin and was calculated with Google Maps	Data documentation (Jepsen and Eberle, in preparation)
Energy consumption processing	Between 0.3 and 1.4 MJ electricity and 0.3 and 2.9 MJ heat from oil and gas per kilogram food; ranges result from different production requirements	GEMIS 4.81
Transport processing-wholesale	100 km lorry transport	GEMIS 4.81
Energy consumption wholesale	Between 0.02 and 0.3 MJ electricity per kg for chilled products and 0.2 and 0.6 MJ electricity for frozen products; ranges result from different storage requirements, storage times and product specifications	GEMIS 4.81
Refrigerants wholesale	Losses of refrigerants between 1.0E−07 and 3.5E−06 kg per kg product; ranges result from different storage requirements, storage times, and product specifications	GEMIS 4.81
Transport wholesale-retailer	100 km lorry transport	GEMIS 4.81
Energy consumption retailer	Chilled products: between 0.2 and 0.4 MJ electricity and 0.2 MJ heat (oil and gas), unchilled products: 0.03 and 0.4 MJ electricity and 0.03 and 0.5 MJ heat (oil and gas), frozen products: 0.1 MJ electricity and 0.1 MJ heat (oil and gas); ranges result from different storage requirements, storage times, and product specifications	GEMIS 4.81
Refrigerants retailer	Losses of refrigerants between 1.1E−06 and 1.4E−06 kg per kg food; ranges result from different storage requirements, storage times, and product specifications	GEMIS 4.81
Energy consumption refrigerators households	Average consumption over diff. refrigerators per year and household 148 kWh	Enercity Stadtwerke Hannover AG (n.y.)
Share of chilled food in the food basket	57 %	Own calculation based on the storage requirements
Energy consumption cooking households	Average consumption over diff. cookers per household and year 373 kWh (gas and electric)	Grießhammer et al. (2010)
Share of cooked food in the food basket	41 %	Own calculation based on the consumption possibilities
Shopping tour	2.4 km transport per kg food	Sima et al. (2012)
Transportation shopping tour	83 % average middle-size car (diesel and gasoline), 3.4 % public transportation (3 % bus and 0.4 % tram), and 13.6 % on foot or bike (no emissions considered)	Sima et al. (2012)

348 km is the average geographical transport distance in Germany. To simplify, this was used also as transport distance for transports to the harbor in all countries of origin

Table 2 Amounts of purchased food, eaten food, and food losses per food item analyzed for in-house food consumption

Product group	Food purchases [kg/cap]	Consumption [kg/cap]	Losses [kg/cap]	Assumptions
Bread and cereals	104.614	93.002	11.612	
Rice	2.395	2.309	0.086	
Bread and baked goods	79.212	68.512	10.700	
Pasta and other cereals	23.007	22.181	0.826	
Meat and meat products	41.503	32.505	8.999	
Bovine and veal meat	7.152	5.602	1.551	Incl. sheep, goat, and other meats, analyzed as beef
Pork meat	7.138	5.591	1.548	Incl. meat without specification, analyzed as pork
Poultry meat	5.406	4.234	1.172	Analyzed as broiler
Meat products	21.807	17.079	4.728	Incl. meat preparations, analyzed as pork, broiler, and beef meats with a further processing step
Fish and fish products	5.485	4.295	1.189	Analyzed as wild fish
Dairy products and eggs	144.059	130.384	13.674	
Milk	118.478	106.844	11.634	Incl. milks and preserved milks produced and other milks and cream-based products, incl. yoghurt
Cheese	9.840	8.874	0.966	Incl. cheese without specification
Cream	4.062	3.663	0.399	
Butter	4.110	3.706	0.404	
Eggs	7.569	7.297	0.272	
Fats and oils	6.972	6.722	0.250	w/o butter
Fruits	60.290	45.212	15.078	
Citrus fruits	9.900	6.880	3.020	Analyzed as oranges
Bananas	14.480	10.064	4.417	Incl. other tropical fruits
Apples	32.958	24.634	8.324	Incl. pears, drupes, pome, berries, grapes, nuts, seeds, dried fruits, and fruits without specification
Canned and frozen fruits	2.952	2.846	0.106	Analyzed as canned and frozen apples
Vegetables and potatoes	87.897	62.912	24.985	
Tomatoes	19.461	13.111	6.350	Incl. capsicum, cucumber, and other fruit vegetables
Fresh vegetables and salad	29.592	19.936	9.656	
Dry, frozen, and canned vegetables	12.726	12.269	0.457	Analyzed as fresh vegetables
Potatoes	26.118	17.596	8.522	
Sugar	5.895	5.684	0.212	Incl. sweetener
Sum	456.715	380.715	76.000	

All input and output data in agricultural production (including methane and nitrous oxide emissions from soils and animal production), food processing, and retailing have been taken from GEMIS 4.81 database. GEMIS datasets cover mainly consumption data, i.e., how much electricity is needed, the amount of fertilizer used, etc. Fertilizer-derived emissions in agriculture as well as emissions from enteric fermentation were calculated in the GEMIS datasets by following Witzke (2010). These modeling choices for the inventory of used products, materials, and phases were adopted in the present study by using the given output data for direct emissions. For example, the amount of emitted greenhouse gases from enteric fermentation was not modeled within this study but taken from GEMIS where enteric fermentation had been modeled. However, regarding input data, an exception has been made with respect to water consumption. As these data are not included in GEMIS, they have been taken from Mekonnen and Hoekstra (2010), but only data for the so-called blue water have been used. Input and output data for the consumption phase are based on data obtained from literature (see Table 1).

Generic environmental data needed like electricity grids, transports, pesticides, and fertilizers have been taken from ecoinvent 3.01 database.

In order to have the possibility to analyze where water consumption and land use are highest due to German food consumption and food losses, water consumption and land use in agricultural production were correlated with their national origins.

For detailed information on the used datasets, see Table 1.

Table 3 Amounts of purchased food, eaten food, and food losses per food item analyzed for out-of-home consumption

Product group	Food purchases [kg/cap]	Consumption [kg/cap]	Losses [kg/cap]	Assumptions
Bread and cereals	26.010	17.010	9.000	
Rice	2.133	1.395	0.738	
Bread and baked goods	3.387	2.215	1.172	
Pasta and other cereals	20.490	13.400	7.090	
Meat and meat products	9.820	6.422	3.398	
Bovine and veal meat	2.707	1.771	0.937	Incl. sheep, goat, and other meats, analyzed as beef
Pork meat	2.702	1.767	0.935	Incl. meat without specification, analyzed as pork
Poultry meat	2.046	1.338	0.708	Analyzed as broiler
Meat products	2.364	1.546	0.818	Incl. meat preparations, analyzed as pork, broiler, and beef meats with a further processing step
Fish and fish products	0.021	0.014	0.007	Analyzed as wild fish
Dairy products and eggs	2.306	1.508	0.798	
Milk	0.036	0.023	0.012	Incl. milks and preserved milks produced and other milk and cream-based products, incl. yoghurt
Cheese	2.076	1.358	0.718	Incl. cheese without specification
Cream	2.076	1.358	0.718	
Butter	7.933	5.188	2.745	
Eggs	5.650	3.695	1.955	
Fats an oils	0.770	0.504	0.266	w/o butter
Fruits	0.220	0.144	0.076	
Citrus fruits	0.196	0.128	0.068	Analyzed as oranges
Bananas	1.098	0.718	0.380	Incl. other tropical fruits
Apples	6.972	4.560	2.412	Incl. pears. drupes, pome, berries, grapes, nuts, seeds, dried fruits, and fruits without specification
Canned and frozen fruits	6.972	4.560	2.412	Analyzed as canned and frozen apples
Vegetables and potatoes	2.441	1.597	0.845	
Tomatoes	0.406	0.265	0.140	Incl. capsicum, cucumber, and other fruit vegetables
Fresh vegetables and salad	0.593	0.388	0.205	
Dry, frozen, and canned vegetables	1.351	0.883	0.467	Analyzed as fresh vegetables
Potatoes	0.091	0.060	0.032	
Sugar	12.776	8.355	4.421	Incl. sweetener
Sum	68.217	44.612	23.605	

2.3.1 Agriculture

In order to calculate the described 23 food products on consumer level, 26 agricultural products were modeled. These are apples, bananas, barley, broilers, corn, eggs, fattening bulls, field vegetables, fish, forage, grass, milk cows, oats, oranges, palm fruits, peas, pigs, potatoes, rapeseeds, rice, soybeans, sugar beets, sugar can, sunflower seeds, tomatoes, and wheat. In agricultural production, energy, land use, production of pesticides, production and use of fertilizers, and water use for irrigation as well as direct emissions for production of plant products for direct human consumption but also for livestock feed have been taken into account. Land use and water consumption have only been taken into account in this life cycle stage. For livestock's breeding feed consumption, transports of feed and energy use were considered as well as direct emissions. Furthermore, the necessary transports to food processing have been included within this life cycle phase. For further details, see Table 1.

2.3.2 Food processing

In food processing, energy use (electricity and heat) and direct emissions (in particular from refrigerator losses) for slaughtering, milling, baking, processing of oil seeds, fruits and vegetables, and processing of dairy products have been considered. Food processing includes also transportation of products to retail. For further details, see Table 1.

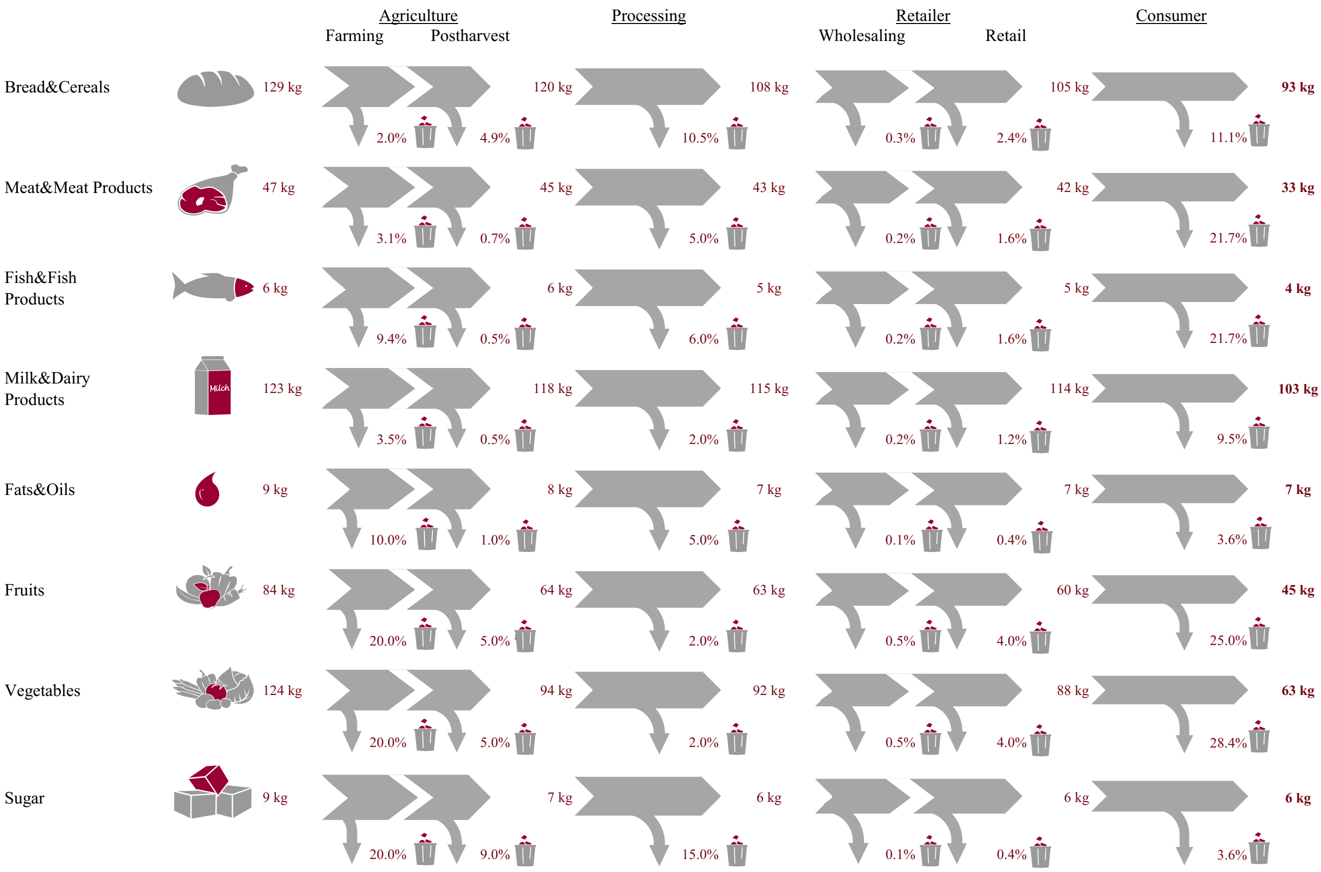

Fig. 1 Material flows of in-house food consumption and food losses per person and year. Data are given in "consumption" weight (e.g., boneless meat and w/o slaughter by-products)

2.3.3 Retailing

In retailing (wholesalers and/or retailers), energy use (electricity and heat) and direct emissions (in particular from refrigerator losses) for storing of chilled, unchilled, and frozen products have been considered. Different storage requirements and storage times have been taken into account. Regarding in-house consumption, also transports between wholesalers and retailers have been taken into account. Regarding out-of-home consumption, transports from the wholesaler to the place of out-of-home consumption have been included. For further details, see Table 1.

2.3.4 Consumption

In in-house consumption, energy use for the shopping trip, the storing, and the cooking of purchased food has been considered. In out-of-home consumption, energy use for the preparing of meals, food storing, and airconditioning of restaurants has been taken into account. Customer transport to the place of out-of-home consumption has not been considered. For further details, see Table 1.

2.4 Simplifications and assumptions

In order to model the food baskets and their product chains, some simplifications had to be done. The main reason for that was the lack of statistics and/or consistent environmental data, but also for modeling reasons (reduction of complexity of food production and distribution chains). The following simplifications have been made:

The statistical food baskets had to be simplified because not for all products distinguished in the statistics have environmental data been available in the used database. Thus, eight product groups with a total of 23 food products have been distinguished.

All food imports are modeled on agricultural level; thus, also all food processing takes place in Germany. This simplification was done because statistical data do not show at which stage of the product's life cycle it is imported and also input/output data for processing in all the countries needed are not available.

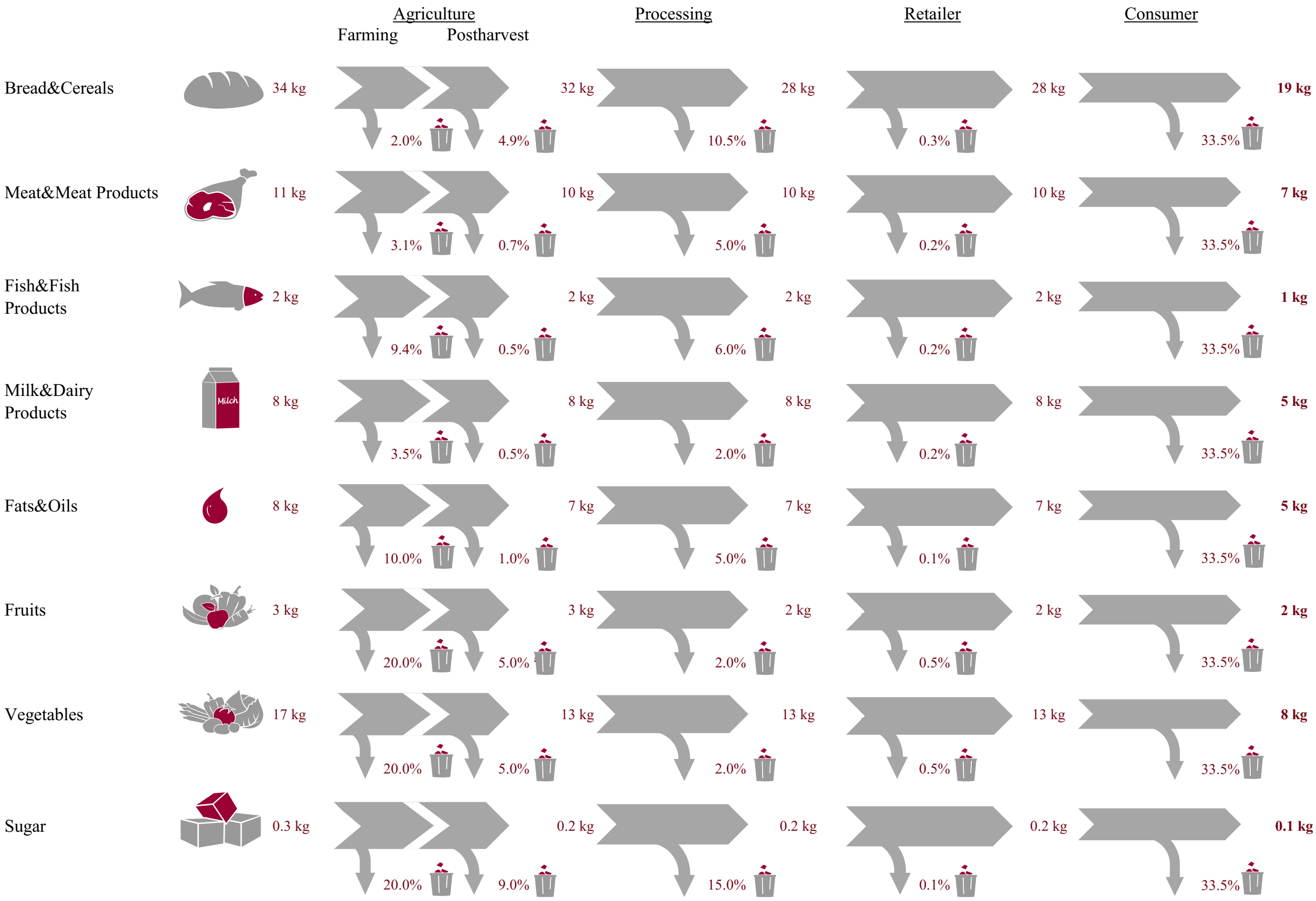

Fig. 2 Material flows of out-of-home food consumption and food losses per person and year. Data are given in "consumption" weight (e.g., boneless meat and w/o slaughter by-products)

Furthermore, it was assumed that input for production of all fodder components (national and international) is done like in Germany. This includes also the same import countries and import shares for each fodder component. This simplification has to be done for two reasons: first, because of actual restrictions of the software program (which hopefully will be solved next time) and, second, because import data for fodder components could not be further analyzed within this project. The composition of the livestock feed was modeled with respect to country-specific data of the country where livestock breeding takes place.

Regarding poultry, the assumption was made that all meat is produced from broilers; the share of laying hens' meat was not considered. The potential impact of that assumption is discussed. In addition, it was assumed that all food imports from overseas

Table 4 LCA results for life cycle phases and in total per person and year

Impact categories	Unit	Agriculture	Processing	Retailing	Consumption	Total
GWP-100a	kg CO_2e	1.56E+03	1.19E+02	5.81E+01	1.02E+03	2.75E+03
Fossil depletion	kg oil-equiv.	2.69E+02	2.56E+01	1.51E+01	4.50E+02	7.59E+02
Freshwater eutrophication	kg P-equiv.	1.64E−01	8.16E−02	5.45E−02	7.33E−01	1.03E+00
Marine eutrophication	kg N-equiv.	9.25E−01	1.57E−01	1.44E−02	2.09E−01	1.31E+00
Metal depletion	kg Fe-equiv.	2.23E+01	1.13E+00	1.00E+00	4.51E+01	6.96E+01
Ozone depletion	kg CFC-11-equiv.	5.90E−05	5.72E−06	3.20E−06	1.25E−04	1.93E−04
Particulate matter formation	kg PM-10-equiv.	2.60E+00	6.81E−02	3.13E−02	9.79E−01	3.68E+00
Photochemical oxidant formation	kg NMVOC	9.66E+00	4.19E+00	3.79E+00	4.51E+01	6.27E+01
Terrestrial acidification	kg SO_2-equiv.	1.48E+01	2.00E−01	8.09E−02	2.58E+00	1.76E+01
Agricultural land use	m^2*a	2.67E+03	–	–	–	2.67E+03
Agricultural water use	l	1.40E+04	–	–	–	1.40E+04

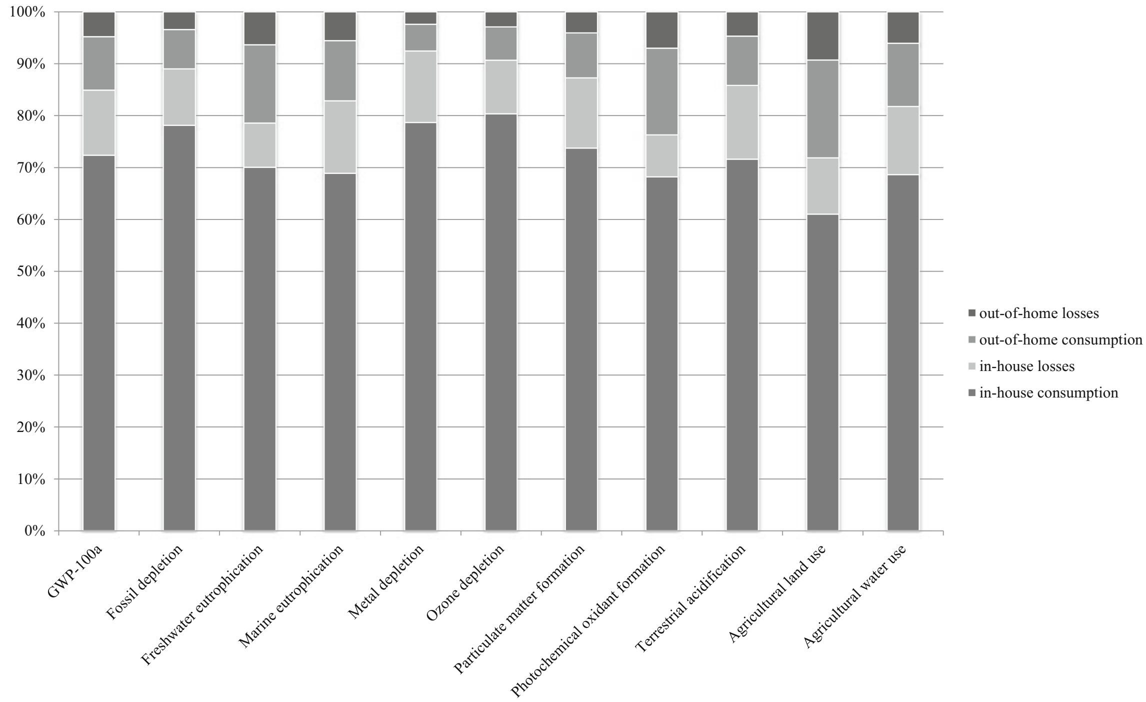

Fig. 3 Shares of in-house and out-of-home food consumption and food losses regarding environmental burdens caused by German food consumption

are carried out only by ship. This simplification was done with respect to the very low relevance of air freight transports of food to Germany which is about 0.12 % of all food imports (Keller 2010).

Moreover, organic production systems are not included also due to their low relevance—only 6 % of the agricultural land in Germany is cultivated regarding standards for organic production (BLE 2012)—and due to the fact that not all data needed have been available for organic production.

Besides, it was assumed that households buy all their food at retailers; purchases direct at the farm or at local markets have not been considered. For out-of-home consumption, it was assumed that all food is delivered by wholesalers.

No statistical data for the origin of consumed rice could be found. German trade statistics show only the import countries of processed rice (e.g., peeled rice). Thus, it was assumed that the world's largest rice exporters export rice to Germany at the same proportion as their share in the global rice market.

In order to reduce the complexity of the model, the treatment of food waste as well as credits for alternative use of food waste (e.g., as animal feed) is not included.

2.5 Allocations

Most agricultural production systems have more than one output. Milk cows, for example, are kept for milk as main product and meat as co-product. In LCAs, environmental burdens need to be

Table 5 Average impact for German food consumption and losses per kilogram consumed product

Impact categories	Unit	Animal products	Plant products
GWP-100a	kg CO_2e	9.21	2.55
Fossil depletion	kg oil-equiv.	2.10	1.00
Freshwater eutrophication	kg P-equiv.	2.78	1.41
Marine eutrophication	kg N-equiv.	4.92	0.85
Metal depletion	kg Fe-equiv.	1.74	1.04
Ozone depletion	kg CFC-11-equiv.	0.53	0.26
Particulate matter formation	kg PM-10-equiv.	1.32	0.28
Photochemical oxidant formation	kg NMVOC	1.69	0.86
Terrestrial acidification	kg SO_2-equiv.	7.15	0.80
Agricultural land use	m^2*a	10.66	1.34
Agricultural water use	l	1.89	3.17

Table 6 National origin of water and land used for agricultural food production per person and year

Country	Unit	Animal products	Plant products	Total	Unit	Animal products	Plant products	Total
Argentina	1	282	0	282	m^2*a	216	0	216
Austria	1	0	9	9	m^2*a	0	1	1
Brazil	1	44	0	44	m^2*a	216	0	216
Colombia	1	0	20	20	m^2*a	0	2	2
Croatia	1	0	344	344	m^2*a	0	2	2
Czech Republic	1	2	7	10	m^2*a	25	20	45
Germany	1	2556	712	3268	m^2*a	1353	317	1669
Denmark	1	6	9	15	m^2*a	3	2	5
Ecuador	1	0	503	503	m^2*a	0	3	3
Egypt	1	0	63	63	m^2*a	0	0	0
Spain	1	0	2521	2521	m^2*a	0	8	8
France	1	381	16	397	m^2*a	15	12	27
Hungary	1	1	0	1	m^2*a	4	0	4
Israel	1	0	160	160	m^2*a	0	0	0
India	1	0	300	300	m^2*a	0	2	2
Italy	1	0	647	647	m^2*a	0	6	6
Maroc	1	0	15	15	m^2*a	0	0	0
Netherlands	1	52	23	75	m^2*a	9	22	31
Pakistan	1	0	2437	2437	m^2*a	0	3	3
Poland	1	8	3	10	m^2*a	17	13	30
Swaziland	1	0	12	12	m^2*a	0	0	0
Thailand	1	0	884	884	m^2*a	0	5	5
Turkey	1	0	126	126	m^2*a	0	0	0
UK	1	1	712	713	m^2*a	2	2	4
USA	1	0	925	925	m^2*a	0	3	3
Vietnam	1	0	293	293	m^2*a	0	4	4
Total	1	3333	10,740	14,073	m^2*a	1861	425	2286

In interpreting the results, it has to be considered that results for animal-based products depend on the assumption that production of fodder components is done like in Germany with the same import countries and import shares for each fodder component. Thus, shares of Germany are somewhat overestimated with respect to water and land use (see Sections 2 and 4)

allocated to the products by different allocation methods (mass, economic, or commodity-specific allocations). In order to reduce the complexity of the model and due to some lacking data, allocations have been made only regarding food losses, where a mass allocation was applied at all life cycle stages. In the case of meat, a physical allocation was done to allocate burdens to meat and slaughter by-products. An economic allocation was renounced because prices, in particular regarding by-products, vary enormously with respect to time and geographical origin and research on this was not part of the present study. Thus, regarding milk cow keeping, an economic allocation was made with the result that 80 % of impacts have been allocated to milk.[4] Also with respect to dairy production, allocations have been made. Here, an allocation with respect to milk solids was chosen, which is regarded as the "fairest" allocation method for dairy products (Lundie et al. 2007). Regarding the production of soy and rape seed shred material flows have been allocated to oil and shred regarding their heating value equivalents, which was the approach chosen in the database used. In all other cases of agricultural production, 100 % product allocation was chosen. This approach leads to a slight overestimation of environmental burdens in agriculture.

In the case of combined power generation, burdens were allocated in relation to energy yield. Environmental burdens have always been allocated between losses and consumption by mass allocation.

2.6 Impact assessment

The impact assessment methodology used is ReCiPe Midpoint (Goedkoop et al. 2009). The following environmental impact categories have been assessed: climate change, fossil depletion, freshwater eutrophication, marine eutrophication, metal

[4] The remaining 20 % have been allocated to mother cow meat but have not been considered further in the model.

Table 7 Environmental impacts due to food losses per kilogram consumed food

Impact categories	Unit	In-house food losses (% of environmental impact per impact category)	Out-of-home food losses (% of environmental impact per impact category)	Total food losses
GWP-100a	kg CO_2e	0.9 (15 %)	2.8 (32 %)	1.1
Fossil depletion	kg oil-equiv.	0.2 (12 %)	0.6 (31 %)	0.3
Freshwater eutrophication	kg P-equiv.	2.3E−04 (11 %)	1.4E−03 (30 %)	3.6E−04
Marine eutrophication	kg N-equiv.	4.8E−04 (17 %)	1.5E−03 (32 %)	6.0E−04
Metal depletion	kg Fe-equiv.	2.5E−02 (15 %)	3.6E−02 (32 %)	2.6E−02
Ozone depletion	kg CFC-11-equiv.	5.2E−08 (11 %)	1.2E−07 (31 %)	6.0E−08
Particulate matter formation	kg PM-10-equiv.	1.3E−03 (15 %)	3.2E−03 (32 %)	1.5E−03
Photochemical oxidant formation	kg NMVOC	1.3E−02 (11 %)	9.4E−02 (29 %)	2.2E−02
Terrestrial acidification	kg SO_2-equiv.	6.6E−03 (17 %)	1.8E−02 (33 %)	7.8E−03
Agricultural land use	m^2*a	0.8 (15 %)	5.3 (33 %)	1.3
Agricultural water use	l	4.8 (16 %)	18.1 (33 %)	6.3

depletion, ozone depletion, particulate matter formation, photochemical oxidant formation, and terrestrial acidification. Furthermore, also the use of agricultural land and agricultural water use for food production has been analyzed. Toxicity indicators have not been assessed mainly because the input data for pesticide use available for the different foods have been very unspecific.

3 Results

The analysis shows that German food consumption emits 2.7 t of greenhouse gases per person each year. Fourteen cubic meters of blue water is used for agricultural food production per person, and 2673 m^2 of agricultural land is occupied each year for each German for food consumption. Table 4 shows total results for each indicator according to life cycle phases.

The results show that agricultural production and consumption are responsible for the main impacts of German food consumption and food losses. For all indicators analyzed, these two life cycle phases cause more than 87 % of the environmental burden. In contrast, food processing and retailing have less environmental impact for all indicators and inventory parameters.

GWP-100, fossil depletion, freshwater and marine eutrophication, metal depletion, and terrestrial acidification are mainly caused by energy use along the products' life cycles and in particular GWP-100 also by emissions directly from agricultural production. Particulate matter formation and photochemical oxidant formation originate mainly from transport emissions.

Eighty-seven percent of food is consumed in-house. In terms of environmental impact, in-house consumption is responsible for 61–80 % (depending on the impact category) of total environmental burdens along the food chain. Food losses due to in-house food consumption have a share in the total (whole food chain) environmental burden between 8 and 14 %.

Total out-of-home food consumption is responsible for 6 to 19 % of the environmental burdens, whereas food losses due to out-of-home consumption range between 2 and 9 %. In-house and out-of home food losses along the food chain have a share of 15 to 21 % of environmental impact of the food basket.

Figure 3 shows the shares in in-house and out-of-home food consumption and food losses regarding environmental burdens of the different indicators and inventory parameters.

Regarding the consumed respectively wasted products, results show that animal products like meat and dairy products cause most of the environmental burden of food consumption and food losses, although the share of plant products is higher regarding amounts of consumption or waste. This is the case for all analyzed impact indicators. Only regarding agricultural water use, plant products consume more water in total and per kilogram product (Tables 5 and 6).

Results per kilogram product (Table 5) show that animal products in the German food basket have a higher impact for all analyzed impact categories and parameters than have plant

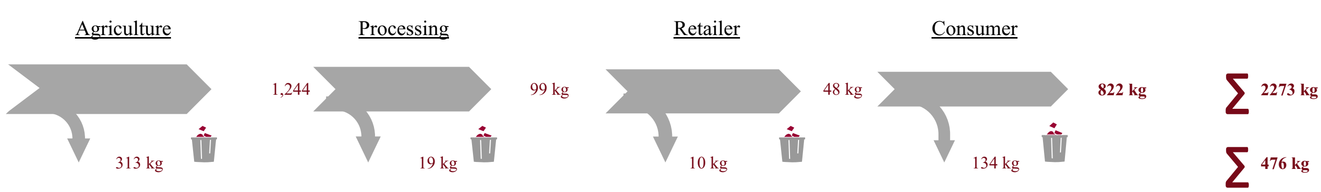

Fig. 4 Greenhouse gas emissions due to German food consumption and food losses per life cycle phase (impact of specific life cycle phase) and in total (sum of impacts of all life cycle phases) per person and year. Mass allocation for allocation between losses and consumption

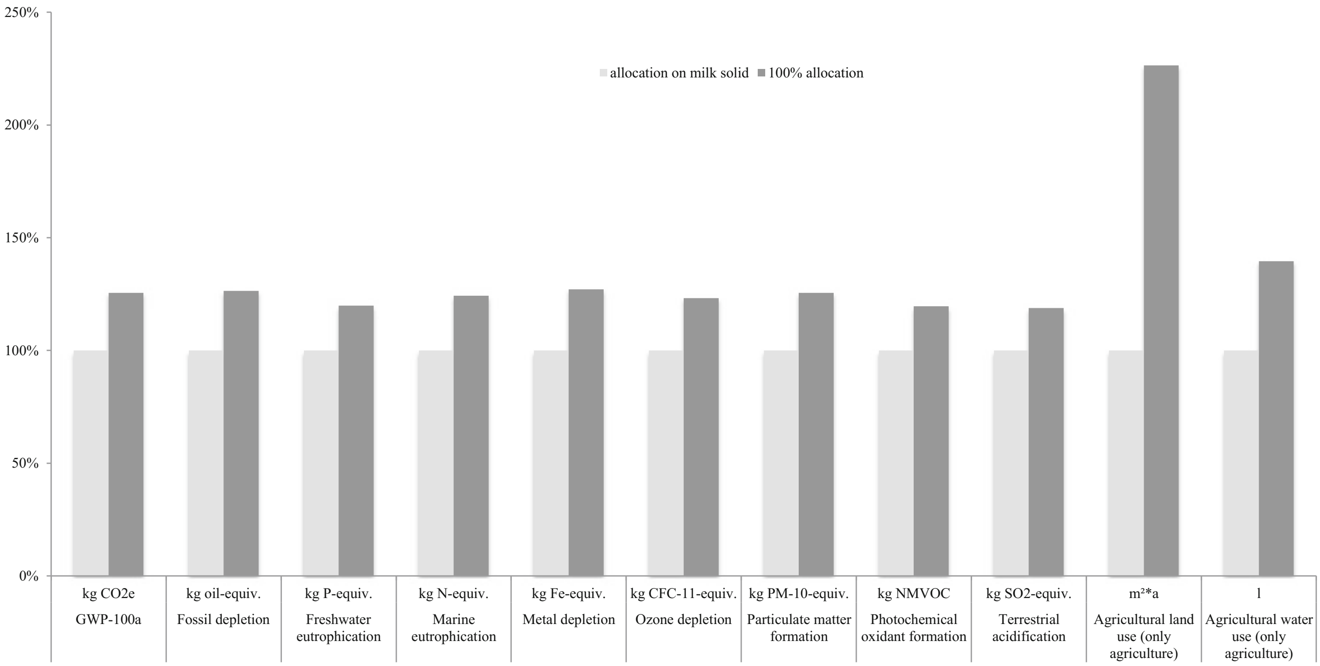

Fig. 5 Differences in results with respect to allocation methods

products in the German food basket. The only exception is water use. In particular, in the case of agricultural land use for food production, this is obvious: for the production of animal products, eight times more land is needed per kilogram than for plant products. Just as with respect to the indicator terrestrial acidification, differences are significant: the impact per kilogram consumed animal-based food is nine times higher than that of products with a plant-based origin. Also for marine eutrophication (six times higher), particulate matter formation (five times higher), and global warming (four times higher), the differences are considerable. For all other indicators the impact of animal products is between 1.7 and 4.7 times higher than that of plant products. Only regarding agricultural water use (irrigation water) for food production is it vice versa: water use for animal products is lower than that for plant products, due to the assumption that fodder is modeled as German fodder, no direct water consumption of animals is considered, and the fact that production of German fodder components needs less water than vegetable production.

Results show that in total most water for German food consumption and losses is used in Germany (23 %) followed by Spain (18 %) and Pakistan (17 %). Results for animal products show that also Germany is responsible for most of the water use (77 %) followed by France (11 %) and Argentina (8 %). In contrast, regarding plant-based food, most water is used in Spain (23 %) followed by Pakistan (23 %) and the USA (9 %) (Table 6).

Regarding land use, most agricultural land is used in Germany (73 %). This is the case for animal (70 %) and plant-based food (75 %). Germany is followed by Argentina and Brazil (both 9 %). This is the same for animal-based products but not for plant-based products where the next highest shares have the Netherlands and the Czech Republic with 5 % each (Table 6).

Table 7 shows the environmental impacts which are caused per kilogram consumed food due to food losses. These are much higher for out-of-home consumption than for in-house consumption.[5] This is mainly due to the fact that losses for out-of-home consumption are much higher than those for in-house consumption, but also because of the differences in the composition of the consumed food. Thus, the high value for per kilogram consumed food for water use is mainly caused by out-of-home consumption, where—regarding our data—much more rice is consumed and spoiled than at in-house consumption. The value for land use is so much higher because of the higher share of waste, but also due to the higher consumption and loss rate of meat.

4 Discussion

Results show a high relevance of food consumption and food losses regarding environmental impacts: e.g., food consumption and food losses cause about 23 % of the German greenhouse gas emissions per person[6] and the water used for

[5] Blumenthal and Göbel (2014) found out that in German communal feeding, food losses add to 8 to 30 % of food consumption in this sector. According to our data, the share in food losses is 33.5 % in out-of-home consumption (see Fig. 2).

[6] http://www.umweltbundesamt.de/themen/klima-energie/klimaschutz-energiepolitik-in-deutschland/treibhausgas-emissionen/europaeischer-vergleich-der-treibhausgas-emissionen; status: 8 May 2014

German food production is about one third of the German households' water use (Destatis 2013) (Fig. 4).

In general, results show a similar dimension as results from previous studies which have been carried out to estimate environmental impacts of German food consumption. However, there are also differences. One reason for that is that in this study both the whole life cycle from agriculture to consumption (including energy consumption for shopping trip, food storage, and cooking) and food losses at all life cycle stages have been considered. This was not the case in previous studies for Germany (Wiegmann et al. 2005; Meier 2014).

Wiegmann et al. (2005) calculated greenhouse gas emissions which are one quarter lower. They used a similar methodology but a different database. The results of Meier (2014) for greenhouse gas emissions are 9 % lower. Meier also used a different database.

There are two main reasons for the differences: one is that Wiegmann et al. (2005) did not calculate all food losses along the value chain, because data have not been available in sufficient detail at that time. Meier (2014) did not calculate energy consumption at household level for the shopping trip, cooling, and cooking. The other reason is that both studies used the GEMIS database for basis data as electricity grid, fertilizer and chemicals production, and transport. In contrast, in this study, the ecoinvent database was used for basis data; GEMIS data were only used for material flows. Compared to the ecoinvent database, greenhouse gas emissions in the GEMIS database are lower in most cases.

Regarding agricultural water use, Meier (2014) calculated much higher values. According to his results, German food consumption is responsible for 32.5 m^3 of water use per person and year which is more than twice as much as the results of this study. The main reason for that is that in Meier's study (Meier 2014), nuts count for about one third of water consumption of German food consumption. In this study, nuts have not been a separate category; they have been subsumed in the category "other fruits," and thus, specific water use of nuts has not been taken into account. This and also other differences regarding the composition of the calculated food baskets explain differences in agricultural water use.

In contrast, with respect to land use, results of Meier (2014), Wiegmann et al. (2005), and Kastner et al. (2012) are about 10 % lower. There are two main reasons for this difference. One is that different data regarding land use have been used in the studies; the other is that food losses have not been taken into account in all studies. Yield data in this study have been taken from GEMIS 4.81,[7] which uses yield data from the Common Agricultural Policy Regionalized Impact Analysis (CAPRI) modeling system[8] in most datasets. GEMIS groups countries into Central, North, West, and South Europe, and Germany has been assigned to Central Europe. Probably, this leads to lower yields than typical for Germany.

Also, for Switzerland, there exists a similar study assessing the environmental impacts of Swiss food and non-food consumption and production. Even though the results are not totally comparable because of a different methodology used[9] and different nutrition habits, results for nutrition show greenhouse gas emissions per Swiss of slightly below 2 t, but does not include energy consumption for the shopping trip, for food storage, and for cooking (Jungbluth et al. 2011). Although results are somewhat lower than those in the study presented here, they are nevertheless in a comparable range.

Beside the comparison of absolute values, also the share of life cycle phases in total environmental burdens can be compared with results of other studies. In particular, food LCA studies (e.g., Milà i Canals et al. 2008) came to the result that agriculture and consumption phase cause for most products most of total environmental burdens.

Furthermore, results of this study have to be discussed against the allocation methods used. For this purpose, a sensitivity analysis has been carried out to analyze the influence of the allocation method used for milk cow keeping and processing of dairy products. In the sensitivity analysis, both allocations have been changed to 100 % allocation. Sensitivity analysis results show that this allocation influences results. With respect to all analyzed impact categories and inventory parameters, results are 3 to 19 % higher with 100 % allocation. In particular, regarding greenhouse gas emissions (8 %), particulate matter formation (9 %), terrestrial acidification (19 %), and agricultural land use (18 %), an effect of the chosen allocation can be shown (Fig. 5). Beside a 100 % allocation and the allocation based on milk solids, several other allocation methods are conceivable, e.g., mass allocation and energy allocation. Although the 100 % allocation faces some problems like double counting and is a kind of extreme scenario, it illustrates the variability of the results and the impact of the chosen allocation method. In further studies, other allocation methods should be tested.

Moreover, results have to be discussed against the assumptions and simplifications made. Thus, with respect to the chosen methodology, it has to be considered that results for animal-based products depend on the assumption that production of fodder components is done like in Germany with the same import countries and import shares for each fodder component. Thus, shares of Germany are somewhat overestimated with respect to water and land use and country-specific differences in fodder production could not be considered. If software restrictions are solved, future studies should apply country-specific input data for fodder production.

[7] http://www.gemis.de

[8] http://www.capri-model.org/

[9] The authors used the Environmentally Extended Input-Ouput Analysis underpinned with LCI data (Jungbluth et al. 2011)

Regarding the provenience of water consumption, it has to be taken into account that in the case of rice, no statistical data for the origin of consumed rice could be found. German trade statistics show only the import countries of processed rice (e.g., peeled rice). Thus, it was assumed that the world's largest rice exporters export rice to Germany at the same proportion as their share in the global rice market. Therefore, more precise trade statistics could change the results in the case of Pakistan. The study shows that plant products consume more water per kilogram than animal products. The reason for that is that fodder production in the used data sets needs little irrigation water.

Due to the assumption that all poultry meat dates from broilers and not from laying hens, the environmental impact of meat products in general and in particular poultry meat is slightly over estimated.

In order to further specify the environmental assessment of food production and consumption, future studies should include detailed assessments not only of pesticide production but also of pesticide use.

Due to the overall aim of the study (Jepsen and Eberle in preparation) in the analysis of environmental impacts, the treatment of food waste was not considered.

5 Conclusions

The study shows the high relevance of food production regarding environmental impacts. In particular, animal products are responsible for high environmental burdens in the German food basket. Losses (animal and plant based) along the product chains have a share between 13 and 20 % in environmental impacts. With respect to reduce environmentally relevant food losses, measures should focus in particular on reducing food waste of animal origin like dairy products and meat. It has to be mentioned that in this study no distinction between avoidable and unavoidable losses has been made due to the target of the overall study of which this screening LCA was a part. A German study on food losses (Kranert et al. 2012) estimated a share of 50 % of food losses as unavoidable. Nevertheless, it is not clear whether this is similarly the share for plant-based and animal-based food. As before mentioned, the characteristic "avoidable" or "unavoidable" is closely correlated with a value system that can change in the course of time. In households or restaurants, the avoidance also depends on the preparation and product. Thus, potato skins could be avoided as food loss when preparing boiled potatoes in their jacket and could not be avoided if preparing boiled potatoes. Nevertheless, a distinction between avoidable and unavoidable losses should be made in the future. The most relevant points for reduction measures are agricultural production and consumption in households and out-of-home. In particular, out-of-home consumption has a high share of spoiled food compared to total food consumption. Out-of-home consumption therefore also provides a good starting point for measures.

Nevertheless, better statistical and also environmental data are needed to improve the quality and reliability of the results.

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